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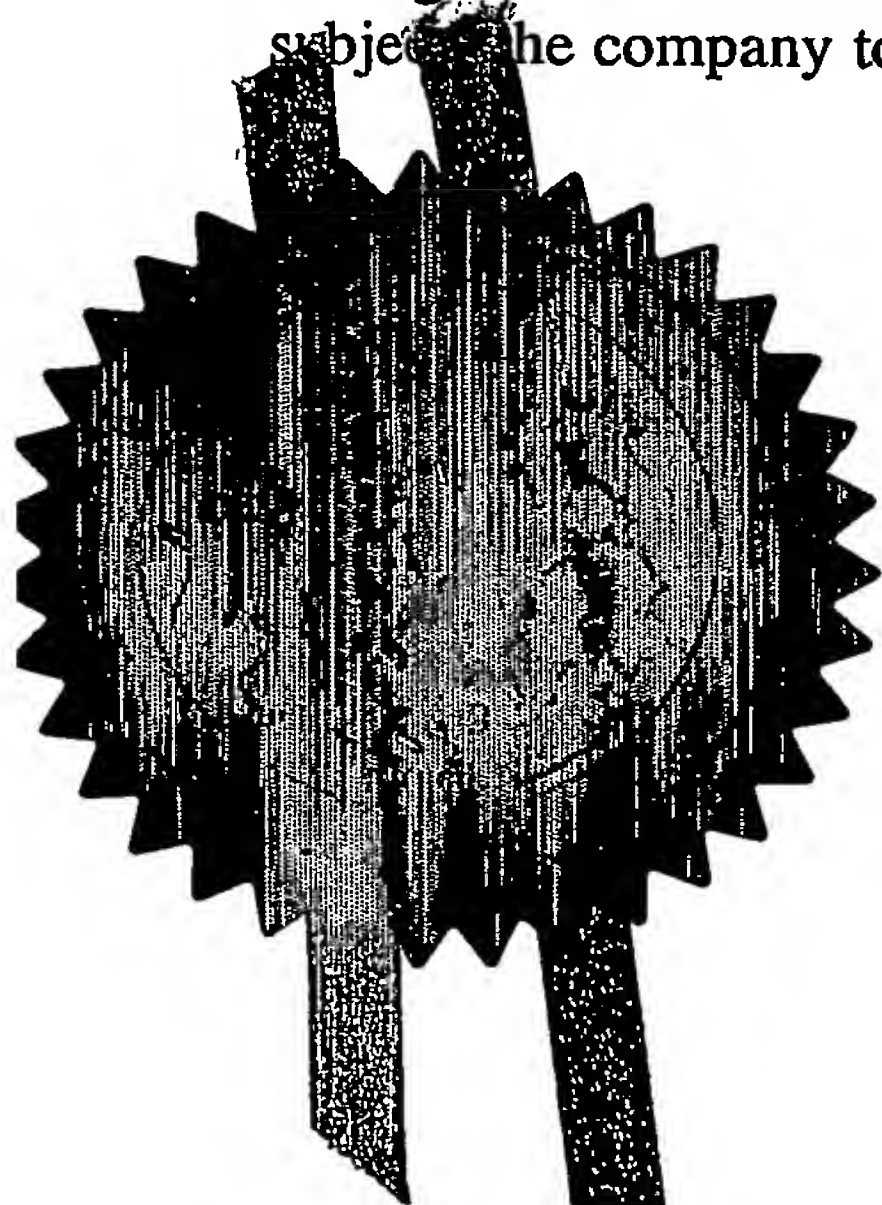
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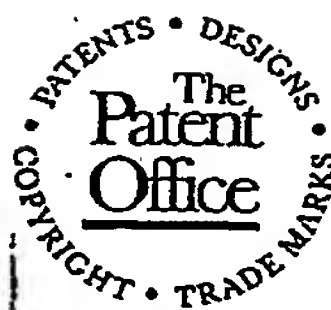
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P01/7700 0.00-0319552.6

# Request for grant of a patent

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The Patent Office

Cardiff Road  
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1. Your reference

P34802-/AMO/PMC/JCO

2. Patent application number

(The Patent Office will fill in this part)

0319552.6

20 AUG 2003

3. Full name, address and postcode of the or of each applicant (underline all surnames)

ReacTec Limited  
ETTC,  
King's Building, Mayfield Road  
Edinburgh  
EH9 3JL, UK

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

828655/1002

United Kingdom

4. Title of the invention

"Improvements in or relating to Vibration Control"

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

Murgitroyd & Company Kennedy's Patent  
Agency Limited  
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Patents ADP number (if you know it)

1198015

08058240002

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)

Date of filing  
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

Yes

- a) any applicant named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
- See note (d))

# Patents Form 1/77

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Continuation sheets of this form

Description 33

Claim(s)

Abstract

Drawing(s) 8 + 8

10. If you are also filing any of the following, state how many against each item.

Priority documents -

Translations of priority documents -

Statement of inventorship and right to grant of a patent (Patents Form 7/77) -

Request for preliminary examination and search (Patents Form 9/77) -

Request for substantive examination (Patents Form 10/77) -

Any other documents (please specify) -

11. -----I/We request the grant of a patent on the basis of this application-----

Signature

Murgitroyd & Company

Date

19 August 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

John Cooper

0141 307 8400

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1 Improvements in or relating to Vibration Control

2

3 The present invention relates to improvements in or  
4 relating to vibration control, and in particular to  
5 a variable damper, a device incorporating a variable  
6 damper and to a method of variably damping relative  
7 motion between two members.

---

8

9 There are many situations where it is desirable to  
10 control or damp the motion between two objects. One  
11 way of doing so is to use a magnetorheological  
12 device, as described for example in US 2,575,360.  
13 Magnetorheological fluid (MRF) contains a suspension  
14 of paramagnetic particles, such that when a magnetic  
15 field is applied, the particles align with the field  
16 thus effectively increasing the viscosity of the  
17 fluid.

18

19 A magnetorheological device typically contains an  
20 electromagnet which generates a magnetic field when  
21 current is passed through its coil. One moving part  
22 can be enclosed within an MRF chamber such that when

10/12/80

1 the magnetic field is applied, there is opposition  
2 to relative motion of that moving part with another  
3 moving part.

4  
5 US 5,492,312 describes a magnetorheological device  
6 wherein a bolt and baffle plate assembly is  
7 contained within an MRF chamber, the fluid in which  
8 can have a magnetic field applied to oppose relative  
9 motion between the assembly and an outer housing,  
10 thus damping motion in up to six degrees of freedom.  
11 An electromagnetic coil is formed around the outer  
12 periphery of the device.

13  
14 However, design considerations have thusfar limited

---

15 the application of magnetorheological devices for  
16 use in devices where the forces that need to be  
17 controlled are relatively high. For a device to  
18 support applications such as those identified, the  
19 off-state force, namely the minimum force required  
20 to induce relative motion between the movable parts,  
21 needs to be low. This is difficult to keep low  
22 because of the high density of the MRF, which can  
23 only be reduced at the expense of its damping  
24 effectiveness when a magnetic field is applied.

25  
26 Furthermore, an electromagnet can be variably  
27 controlled such that the magnetorheological device  
28 provides varying levels of damping. However, for  
29 such control to be properly refined, there is a  
30 requirement that the forces that would be expected  
31 to be applied to the device in use fall within the  
32 force bandwidth, namely the off-state force and the



1 opposition force provided when the electromagnet is  
2 fully activated.

3

4 Examples of applications where there are no such.  
5 effective solutions include skis, snowboards, and  
6 other sporting equipment such as golf clubs, tennis  
7 rackets, polo mallets, and in power tool  
8 applications such as drills for industrial of  
9 domestic purposes.

10

11 The inventors of the present invention have  
12 previously described a vibration control system that  
13 is of particular effectiveness to skis, as published  
14 under number WO 03/049821. Here, MRF flex actuators  
15 are provided to provide single axis control.

16 However, this solution does not provide effective  
17 multi-axis control, as may be required in other

---

18 applications such as snowboards.

19

20 According to a first aspect of the present  
21 invention, there is provided a variable damper  
22 comprising;

23 an outer member comprising a magnetically  
24 conductive sleeve, and

25 an inner member comprising an electromagnet;  
26 wherein

27 a chamber between the outer and inner members  
28 is at least partially filled with magnetorheological  
29 fluid (MRF), such that when a magnetic field is  
30 applied to the chamber, the effective viscosity of  
31 the fluid increases such that relative motion of the  
32 inner and outer members is opposed;

1       the region between the electromagnet and the  
2 sleeve defining a control region in which the  
3 magnetic field is concentrated.

4  
5 According to a second aspect of the present  
6 invention, there is provided a method of variably  
7 damping relative motion between an outer member  
8 comprising a magnetically conductive sleeve and an  
9 inner member comprising an electromagnet, wherein a  
10 chamber between the outer and inner members is at  
11 least partially filled with magnetorheological fluid  
12 (MRF), the method comprising the step of applying a  
13 magnetic field to the chamber, increasing the  
14 effective viscosity of the fluid increases to oppose  
15 the relative motion of the inner and outer members,  
16 where the region between the electromagnet and the  
17 sleeve defining a control region in which the  
18 magnetic field is concentrated.

19  
20 As described below, the sleeve provides a return  
21 path for the magnetic flux.

22  
23 Preferably, the sleeve comprises two end surfaces,  
24 each in a plane perpendicular to the central axis of  
25 the electromagnet and spaced outwardly from an end  
26 of the electromagnet, and a body surface centred  
27 around the axis of the electromagnet and spaced  
28 outwardly from the electromagnet.

29  
30 Preferably, in a rest position in which no magnetic  
31 field is applied, each end surface is at a first  
32 distance from an end of the electromagnet, and the

1 body surface is at a second distance from the  
2 electromagnet.

3

4 The first and second distances represent variables  
5 that define the size and shape of the control  
6 region. Here, the distances as measured from the  
7 electromagnet are the distances that are relevant.  
8 However, the electromagnet may be encased within a  
9 housing, and the first and second distances may be  
10 more conveniently defined as being the distances  
11 between the housing and the sleeve.

12

13 Preferably, the first and/or second distances can be  
14 minimised in order to reduce at least one degree of  
15 freedom of the relative motion of the inner and  
16 outer members.

17

---

18 Preferably, the outer perimeter of the chamber is  
19 bounded by an inner surface of the outer member, a  
20 portion of the perimeter of the sleeve, and a seal  
21 portion of the inner member.

22

23 Preferably, the inner member comprises  
24 interconnected first and second shaft portions, the  
25 longitudinal axes of which, when the inner and outer  
26 members are in a relative rest position, define a  
27 centre axis of the damper.

28

29 Preferably, a housing comprising the electromagnet  
30 is interposed between the first and second shaft  
31 portions.

32



1     Optionally, the inner member comprises a shaft about  
2     which the electromagnet is mounted. Most  
3     preferably, a diaphragm seal is provided at each end  
4     of the shaft to bound the chamber.

5  
6     Preferably, the shaft is magnetically inert.

7  
8     Preferably, the seal portion has an elasticity to  
9     allow the inner member to rotate in planes  
10    perpendicular to the seal portion.

11  
12    Optionally, the seal portion has an elasticity to  
13    reduce at least one degree of freedom of the  
14    relative motion of the inner and outer members.

15  
16    Preferably, the seal portion comprises a sprung  
17    collar and a diaphragm seal.

18  
19    Preferably, the device comprises an elastic end stop  
20    to protect the device from damage induced from  
21    vibrations in the case where the electromagnet  
22    fails.

23  
24    According to a third aspect of the present  
25    invention, there is provided a device incorporating  
26    a variable damper in accordance with the first  
27    aspect.

28  
29    Preferably, the inner and outer members of the  
30    damper are configured to be suitable for attachment  
31    to device components, such that the application of  
32    relative forces between the components results in

1 corresponding forces being applied to the inner and  
2 outer members of the damper.

3

4 Preferably, a parasitic power generator is  
5 incorporated within or on the device to provide the  
6 electric current that drives the electromagnet.

7

8 Preferably, the power generator comprises a  
9 plurality of power generating units that are arrayed  
10 on the device at points where concentrated load  
11 would be expected to be applied to the device when  
12 it is put to use.

13

14 Preferably, the units comprise piezoceramic  
15 material. Optionally, the units could comprise  
16 piezoelectric unimorph or bimorph material.

17

18 Preferably, the device comprises at least one sensor  
19 that detects a variable, the value of which can be  
20 used to determine a desired amount of electric  
21 current to be applied to the electromagnetic coil.

22

23 The current applied to the coil can be varied in  
24 order to vary the strength of the magnetic field.  
25 In turn, the effective increase in the viscosity of  
26 the MRF, and hence the amount of damping between the  
27 inner and outer members provided by the damper, is  
28 dependent on the strength of the magnetic field.  
29 Thus, the desired amount of electric current that is  
30 determined when a particular value of the variable  
31 is detected can be representative of the desired

1 amount of damping that should be applied given that  
2 value.

3

4 Preferably, an intelligent control unit (ICU) is  
5 provided, which is capable of receiving input  
6 signals from the sensors and outputting command  
7 signals to the damper.

8

9 Preferably, an algorithm is used by ICU to determine  
10 a desired relationship between the input signals and  
11 the command signals.

12

13 Preferably, the device is a snowboard, one of the  
14 outer member and inner member of the damper is  
15 attached to the surface of the board, and the other  
16 of the inner member and outer member is attached to  
17 a raised portion formed on the board.

18

19 Preferably, the centre axis of the device is  
20 transversely oriented with respect to the  
21 longitudinal axis of the board.

22

23 Preferably, the centre axis of the device is  
24 parallel with the longitudinal axis of the board.

25

26 Preferably, a plurality of dampers are attached to  
27 the board. Dampers may be provided which have a  
28 mixture of centre axis orientations as above.

29

30 Preferably, torsion forks are provided on the board  
31 and connected to the inner member of the device to  
32 enable control of torsional stiffness of the board.

1  
2 Preferably, a piezoceramic power generating unit is  
3 provided at a binding assembly.  
4

5 The binding assembly is the point at which a boarder  
6 would clip their boots into the board.  
7

8 Optionally, the device is a golf club, one of the  
9 outer member and inner member of the damper is  
10 attached to the shaft of the club, and the other of  
11 the inner member and outer member is attached to or  
12 forms the grip of the club.  
13

14 Optionally, the device is a handle which is a  
15 component of a machine:  
16

17 Such a "machine" may include, for example, a tennis  
18 racket, polo mallet or other sports implement, or  
19 may be a household tool such as a power drill, or  
20 may be a bicycle or motorcycle, with the device  
21 being the handlebar.  
22

23 Embodiments of the present invention will now be  
24 described, by way of example only, with reference to  
25 the accompanying drawings, in which:  
26

27 Fig. 1 shows a partial cross-sectional view of a  
28 variable damper in accordance with a first  
29 embodiment of the present invention;  
30

1 Fig. 2 shows a side view and a sectional view of a  
2 variable damper in accordance with a second  
3 embodiment of the present invention;

4  
5 Fig. 3 shows an isometric section of a sprung collar  
6 used in the damper of the damper shown in Fig. 2;

7  
8 Fig. 4 shows a side view and a sectional view of a  
9 variable damper in accordance with a third  
10 embodiment of the present invention;

11  
12 Fig. 5 shows an isometric section of the damper  
13 illustrated in Fig. 4;

14  
15 Fig. 6 shows a sectional view of a variable damper  
16 in accordance with a fourth embodiment of the  
17 present invention;

18  
19 Fig. 7 is an isometric view of an integrated spring  
20 used with the damper illustrated in Fig. 6;

21  
22 Fig. 8 shows a snowboard incorporating two variable  
23 dampers;

24  
25 Fig. 9 shows a plan cutaway view of a variable  
26 damper in accordance with a fifth embodiment of the  
27 present invention, mounted transversely on a board;

28  
29 Figs. 10 and 11 illustrate how the damper of Fig. 9  
30 is mounted on a board;

31



1 Fig. 12 shows a partial cross sectional view of a  
2 variable damper in accordance with a sixth  
3 embodiment of the present invention, mounted  
4 longitudinally on a board;  
5

6 Fig. 13 illustrates how the damper of Fig. 12 is  
7 mounted on a board;  
8

9 Fig. 14 shows a control schematic for the damper as  
10 illustrated in Fig. 9;  
11

12 Fig. 15 shows a control schematic for the damper as  
13 illustrated in Fig. 12; and  
14

15 Fig. 16 illustrates a seventh embodiment of a  
16 variable damper, as applied for use with a golf  
17 club.

18  
19 Fig. 1 illustrates a first embodiment of the present  
20 invention. A variable damper (also called an  
21 "actuator" or an "MRF device") 10 comprises an outer  
22 portion 12 and an inner portion 14. The inner  
23 portion 14 comprises a first portion 16, second  
24 portion 18, and an electromagnet 20. Power lines 22  
25 are provided within the first portion 16 to power  
26 the coil 24 of the electromagnet 20.  
27

28 The first 16 and second 18 portions have seals 15,  
29 which, together with an inner surface of the outer  
30 portion 12 define an MRF chamber 28. When electric  
31 current flows through the electromagnet coil 24, a  
32 magnetic field 28 is induced, which has the effect

1 of increasing the effective viscosity of the MRF in  
2 the chamber 28, the increase being dependent on the  
3 power of current being passed through the coil 24.  
4

5 Inner seals 15 and outer seals 17 together define  
6 the seal portion of the inner member 14. Any  
7 suitable form of seal may be used, suitably a  
8 diaphragm grommet seal.  
9

10 Fig. 2 shows a second embodiment of the invention,  
11 which differs from that shown in Fig. 1 in that the  
12 seal portion is provided by a sprung collar 90 and  
13 diaphragm seal 92 at opposite ends of the inner  
14 portion.  
15

16 Fig. 3 shows an isometric view of the arrangement of  
17 Fig. 2. ....

18  
19 Insertion of a sprung collar between the inner axle  
20 and outer cylinder provides resistance to movement,  
21 proportional to the stiffness of the spring in a  
22 particular axis. The MR fluid, electromagnet and  
23 sleeve (or cylinder) adds control of dynamic  
24 movement.  
25

26 The sprung collar provides primary control in two  
27 axes orthogonal to the central axis and secondary  
28 control along the central axis.  
29

30 In an alternative embodiment, the sprung collar may  
31 be replaced by a sprung bush. This embodiment is  
32 illustrated in Figs. 4 and 5.

1

2 In further alternative embodiments which are not  
3 illustrated herein, the sprung collar may have a  
4 rectangular or square cross-section.

5

6 The incorporation of sprung collars or bushes  
7 between the inner axle and outer cylinder has a  
8 number of benefits in many applications, including;

9

10 1. To resist deflection of the inner relative to the  
11 outer up to a specified off state force.

12

13 2. To return the inner and outer to their neutral,  
14 rest separation.

15

16 3. To ensure the inner and outer do not actually  
17 touch.

18

19 4. To control axial movement.

20

21 Items 1 and 3 are conflicting requirements, so  
22 therefore, a mechanical end-stop may be additionally  
23 specified (to prevent the inner touching the outer),  
24 should it not be possible with the same spring to  
25 provide a low off state force and ensure clearance  
26 is maintained.

27

28 The spring constant does not necessarily have to be  
29 equal at either end of the cylinder. This presents  
30 the opportunity to control axial movement, with  
31 resistance to movement (between the inner axle and  
32 outer cylinder) at one end of the MRF device being

1 greater or less than the resistance at the other  
2 end.

3  
4 Fig. 6 shows a third embodiment of the present  
5 invention, in which diaphragm seals are provided as  
6 part of a piston. The seals are connected by the  
7 input shaft which runs through the electromagnet.  
8 Fig. 7 shows an isometric view of this embodiment.

9  
10 The control volume of MR fluid is constant between a  
11 fixed electromagnet (EM) core and the magnetic flux  
12 return guide (see figure 6). The electromagnet is  
13 fixed inside the outer cylinder - mounted inside the  
14 steel sleeve that acts as the magnetic flux return  
15 guide. The input shaft (connected to the vibration  
16 source) runs through the centre of the EM core, with  
17 ~~opposing diaphragms connected to the shaft and~~  
18 sealing the system. Movement of the input shaft  
19 relative to a fixed outer cylinder (connected to the  
20 structure to be damped against) results in a  
21 pressure change in the MR fluid chamber - driving  
22 the fluid around the fixed EM core, in the annular  
23 orifice between the core and the sleeve.

24  
25 Activation of the electromagnet controls the flow of  
26 MR fluid around the electromagnet. Increasing power  
27 to the electromagnet results in an increase in  
28 apparent viscosity of the MR fluid between the EM  
29 core and sleeve. Exposing the control volume of MR  
30 fluid to a variable strength magnetic field enables  
31 the control volume to act as a flow control valve.  
32 Increasing resistance to fluid flow enables the

1 device to absorb more energy from vibration induced  
2 movement of the input shaft relative to the outer  
3 cylinder.

4  
5 Connecting the input shaft to opposing diaphragms  
6 (with a solid collar around the input shaft at  
7 either end, to act as a piston) ensures pressure  
8 induced by movement of the input shaft is equal in  
9 both directions (i.e., up and down when considering  
10 figure 6)

11  
12 The movement of fluid from regions experiencing  
13 relatively small magnetic field into the control  
14 region helps to reduce degradation in the  
15 performance of the fluid (i.e., as a result of in-  
16 use-thickening).

17  
18 One primary and two secondary degrees of freedom can  
19 be controlled with the connected diaphragm actuator.  
20 The primary degree of freedom is with the input  
21 shaft reciprocating relative to the outer cylinder  
22 (i.e., up and down when considering figure 6).  
23 Additionally, pitch and yaw about the common central  
24 axis of this axis-symmetric actuator can be  
25 controlled (i.e., limited rotational movement about  
26 two axes orthogonal to the common central axis).  
27 This is largely possible due to specification of a  
28 diaphragm seal, which is a fundamental part of the  
29 piston that induces pressure driven flow of the MR  
30 fluid around the EM core.

31



1 The input shaft runs through the electromagnet core,  
2 but is not connected to it (see figure 7). To  
3 achieve control in three degrees of freedom the  
4 input shaft is machined from a magnetically inert  
5 material, so that its movement is not influenced by  
6 the electromagnet.

7  
8 Control of movement of the input shaft relative to  
9 the outer cylinder may be advantageous. This can be  
10 achieved by guiding the input shaft through the EM  
11 core. A sprung collar / bush between the outside  
12 diameter of the input shaft and the inside diameter  
13 of the EM core can be specified to control movement  
14 of the input shaft against the EM core (i.e.,  
15 lateral movement when considering figure 6).

16  
17 Additionally, damper mounts (illustrated in figure  
18 6) on the outer cylinder may be made from rubber and  
19 specified to act as an end-stop to prevent movement  
20 of the structure connected to the input shaft  
21 against the structure to which the outer cylinder is  
22 fixed. Therefore, rubber damper mounts around the  
23 outer cylinder can act as a mechanical failsafe,  
24 should the electromagnet fail. Due to the damage  
25 that may be caused should a vibration control system  
26 fail, such a mechanical failsafe should be  
27 considered a necessity in a number of applications  
28 of the device.

29  
30 Reference is now made again to Fig. 1, bearing in  
31 mind that reference to components in Fig. 1 can also

1 be applied where appropriate to the other  
2 embodiments illustrated.

3  
4 Controlling the viscosity of the MRF means that the  
5 damping of relative motion between inner and outer  
6 portions 12, 14 can be controlled.

7  
8 A steel (or other magnetically conductive material)  
9 sleeve 30 is mounted internally in the outer portion  
10 12, which provides a flux return path through the  
11 electromagnet 20 for the magnetic field. This has  
12 the effect of concentrating the magnetic field in a  
13 region 32 between the inner and outer portions 12,  
14 14, defining a control volume of MRF within the  
15 chamber 28 that acts as a control region. It is the  
16 variation of the viscosity of this control volume

~~17 that is critical to controlling the damping. MRF in~~  
18 the remaining volume of the chamber 28 is not  
19 activated by the magnetic field when it is applied.

20

21 The chamber 28 is bounded by the outer member 12,  
22 rather than the sleeve 30. Thus, the volume of the  
23 MRF in the device is larger than the control volume.

24

25 This ensures that fluid in the control volume can be  
26 recycled with fresh fluid as the inner member 14 is  
27 moved relative to the outer member 12, the MRF in  
28 the control volume being moveable away from the  
29 electromagnet to a region of the MRF chamber that is  
30 substantially outside the magnetic field. This re-  
31 circulation of the fluid reduces the likelihood of

1 fluid-particle separation and in-use thickening, to  
2 improve the longevity of the device.

3

4 The housing that includes the sleeve 30 can be made  
5 from a single component, where the outer housing is  
6 made from steel and provides the field return path  
7 (Fig. 9), or up to three components, where the steel  
8 sleeve 30 is assembled between split cylinder that  
9 makes the outer housing (Fig. 1).

10

11 This simple construction reduces the number of  
12 moving components, making the damper 10 easy to  
13 manufacture, and also making it durable.

14

15 The electromagnet comprises copper wire wound around  
16 a steel core mounted on an inner axle. Therefore,  
17 the magnetic flux generator is axis-symmetrically

18 mounted with the MR fluid between it and an outer  
19 cylinder to which a steel (or other magnetically  
20 conducting material) cylinder is internally mounted  
21 - providing a flux return path (to the  
22 electromagnet, through the MR fluid).

23

24 Mounting the electromagnet on the axle is considered  
25 the most power efficient means of generating  
26 magnetic field in the system. Prior devices, in  
27 which a coil is wound around the outer cylinder with  
28 a magnetically conductive piston mounted on the axle  
29 to complete the magnetic circuit, require  
30 considerably more power in order to generate a  
31 comparable magnetic field with the device thus  
32 constructed.

1  
2 The embodiments shown provide for multi-axis  
3 control. Two translational degrees of freedom are  
4 provided, as the inner portion 14 translates in a  
5 direction along an axis running from left to right  
6 of the device 10, or in a direction along an axis  
7 extending normal to the page, as illustrated in Fig.  
8 1.

9  
10 When a magnetic field is applied, the resistance to  
11 this relative translational motion that is provided  
12 by the MRF is known as a pressure driven flow mode.

13  
14 Activation of an electromagnet produces an apparent  
15 change in viscosity in MRF exposed to the generated  
16 magnetic field. As the MR fluid becomes more  
17 viscous, more force is required to generate a

---

18 pressure that causes the fluid to flow around a  
19 constriction. The movement of the electromagnet on  
20 the inner axle relative to the outer steel sleeve  
21 creates a constriction and (pressure driven) fluid  
22 flow can be controlled (like a valve) as the  
23 electromagnet activates the MR fluid.

24  
25 There is also a rotational degree of freedom for  
26 relative rotation about a central axis 34 of the  
27 device 10.

28  
29 When the two portions 12, 14 attempt to rotate  
30 relative to each other in this way, the MRF resists  
31 the movement by a shear force that is induced at the  
32 surfaces of the chamber 28. This can be known as

1 the direct shear mode of damping control. The  
2 strength of resistance to motion offered by the  
3 direct shear mode is much less than the strength  
4 offered by the pressure driven flow mode.

5  
6 The inner member 14 comprises a first portion 16, a  
7 second portion 18, and a housing containing the  
8 electromagnet 20. These portions are integral, and  
9 the longitudinal axes of the first and second  
10 portions are in-line and define a central axis 34  
11 both of the inner member 14 and the device 10.

12  
13 Seals 15, 17 provide sufficient elasticity for the  
14 shaft of the inner member to rotate about an axis  
15 running into and out of the page of the device as  
16 illustrated in Fig. 1 (i.e. moving  
17 clockwise/anticlockwise in the figure), and about an  
18 axis running from left to right horizontally as  
19 illustrated in Fig. 1 (i.e. tilting into and out of  
20 the page in the figure).

21  
22 Movement between the inner 14 and outer 16 portions  
23 in a direction along the central axis 34 of the  
24 device is limited in its extent by the seals.

25  
26 Spring return to the neutral position results from  
27 the viscoelastic property of the seals / with sprung  
28 collars located between seals, against the inner and  
29 outer (i.e., in the space between the shaft and the  
30 outer housing).

31



1 Thus, the two translations at right angles to the  
2 shared central axis (of the inner axle and outer  
3 cylinder), plus pitch and yaw about the same axis  
4 can be considered as being four primary degrees of  
5 freedom that can be controlled, while one  
6 translation of the inner member relative to the  
7 outer member along the shared axis and one rotation  
8 about the same axis (assuming the diaphragm seal is  
9 assembled to rotate with the inner axle) can be  
10 considered as two secondary degree of freedom can be  
11 controlled. The secondary degrees of freedom are  
12 limited by the seals.

13

14 One advantage of the damper described above lies in  
15 its ability to provide control of dynamic movement  
16 over a range (i.e., a control bandwidth). The  
17 control bandwidth is between the off state (no power  
18 to the electromagnet; fluid not activated) and the  
19 on state (electromagnet fully on; fluid fully  
20 activated).

21

22 It is important that off-state force is sufficiently  
23 low for the control bandwidth of the MRF device to  
24 act over the operating range of the product to which  
25 it is fitted. Should the off-state force (required  
26 to move the MRF device) be outside or near the upper  
27 limit of the operating range, the control bandwidth  
28 of the MRF device is of little benefit to the  
29 product to which it is fitted, and a passive  
30 vibration control solution would be better  
31 considered.

32

1

2 A low off state force capability can be achieved by:

3 1. Reducing the viscosity of the MR fluid, while  
4 avoiding significant reduction in the % volume of  
5 carbonyl iron content (that would reduce the on  
6 state capability).

7 2. Increasing the gap between the electromagnet and  
8 the steel sleeve / cylinder, without increasing  
9 the gap to an extent that the magnetic field  
10 strength (generated with the electromagnet  
11 activated) becomes dissipated - i.e., reducing  
12 the on state capability.

13 3. Specifying seals with sufficient elasticity to  
14 maintain the MR fluid stays in the outer  
15 cylinder, but avoids significant energy being  
16 absorbed by the seals as the inner is forced to  
17 move relative to the outer.

18

19 The MRF device of the present invention operates  
20 with a low viscosity fluid to ensure a low off state  
21 force is maintained. Concerns with settling and in-  
22 use-thickening (where the activated MR fluid  
23 degrades to a paste-like consistency) are  
24 significantly reduced if the MR fluid in the control  
25 volume and particularly the control region can be  
26 re-circulated (i.e., with MR fluid not exposed to  
27 the magnetic field).

28

29 The variable damper of the present invention has a  
30 wide range of applications, and the scope of the  
31 invention should not be construed as being limited  
32 to a particular application. As a particular

1 example, the invention will now be described as is  
2 incorporated in a snowboard.

3  
4 This application is shown generally in Fig. 8. A  
5 board 40 has bindings 42 with shim portions 44, to  
6 which the outer portion 12 of a damper (or  
7 "actuator") 10 is attached. The inner portion 14 of  
8 the damper 10 is attached to the board 40. Torsion  
9 forks 46 are also mounted on the board 40, and are  
10 also in communication with the inner portion 14 of  
11 the damper 10.

12  
13 As is described in more detail below, sensors  
14 monitor dynamic movement and provide input to an  
15 intelligent control unit (ICU) made up of one or  
16 more microprocessors. The response (i.e., energy  
17 absorbing capability) of the MRF actuator(s)  
18 controls dynamic movement of the product with a view  
19 to optimising performance/tuning the system to suit  
20 the operator (player).

21  
22 The multi-axis system subject to this application  
23 aims to provide a wide bandwidth of semi-active  
24 damping. The system will enable the level of  
25 vibration energy absorption to be adapted with  
26 respect to vibration impulses (i.e., the product of  
27 force and time) and can be tuned to suit the user.

28  
29 Soft flex, torsionally flexible boards are easier to  
30 turn and better to control at lower speeds and are  
31 generally better off piste. Stiff, torsionally  
32 rigid boards have greater stability at speeds and

1 have enhanced carving ability - making it easier to  
2 place the board in a turn at speed. The present  
3 invention is capable of adapting the stiffness and  
4 torsional characteristics with respect to speed and  
5 snow condition. This is achievable by using  
6 integrated sensors to monitor the amplitude and time  
7 response of vibrations that can be used to  
8 characterise speed and surface condition, with an  
9 algorithm programmed into a microprocessor  
10 controlling power supply to the electromagnets that  
11 adapt the energy absorbing capability of the MRF  
12 actuator(s).

13  
14 The actuator must be mounted so that torsional and  
15 longitudinal movement of the board can be  
16 transmitted through the actuator.

17

---

18 For a snowboard, the actuator can be mounted with  
19 its central axis 34 either transverse or parallel  
20 ("in-line") to the longitudinal axis of the board  
21 40.

22  
23 Fig. 9 shows a fifth embodiment of the present  
24 invention, namely a transversely mounted actuator  
25 50. Components of the actuator 50 are similar to  
26 the components referred to in Fig. 1 and shall not  
27 be hereinafter described in detail. The reference  
28 numerals that apply to Fig. 1 can be taken to refer  
29 to the corresponding components in Fig. 9. The same  
30 comments apply for the sixth embodiment illustrated  
31 in Fig. 12, which is described below.

32

1 The sprung collar illustrated in Figs. 2 and 3, or  
2 the bush illustrated in Figs. 4 and 5, are not  
3 essential parts of the MRF device when it is  
4 incorporated in to a snowboard, as the board acts as  
5 the spring that is to be controlled. MRF devices  
6 with sprung collars or bushes would add to the  
7 stiffness matrix of the board and provide adaptive  
8 semi-active control of dynamic movement. On the  
9 snowboard, the actuator is returned to a neutral  
10 position as the board relaxes after being deflected  
11 (assuming the board does not become permanently  
12 deformed).

13

14 Fig. 9 is a plan view of a transversely mounted  
15 actuator 50. The electromagnet 20 is powered by  
16 power supply 52. The MRF chamber 28 is attached to  
~~17 the board 40, and the outer portion 12 of the~~  
18 actuator 50 is attached to the shim 44 (not shown).

19

20 Steel sleeve 54 is attached to the outer cylinder 56  
21 of the outer member, and has the shape of a  
22 cylindrical body portion with two washer shaped end  
23 portions at each end of the cylinder, the outer  
24 edges of which are in line with the outside  
25 perimeter of the body portion. The electromagnet 20  
26 is mounted on an axle and positioned inside the  
27 steel cylinder 54.

28

29 The inner axle and outer cylinder share a common  
30 axis. There is an defined gap between the  
31 electromagnet and the steel cylinder, comprising a  
32 first dimension X, being the distance between the



1 end of the electromagnet 20 and the inner wall of  
2 the steel cylinder 54, and a second dimension Y,  
3 being the distance between the inside diameter of  
4 the steel cylinder 54 and the outside diameter of  
5 the electromagnet 20.

6  
7 The gaps as defined by the dimensions X and Y enable  
8 the device to control up to six degrees of freedom.

9  
10 To minimise the off state force, X and Y should be  
11 made as large as possible, bearing in mind that  
12 their increase will result in a corresponding  
13 decrease in the force that can be provided by the  
14 device once the full on state is applied.

15  
16 Fig. 10 and 11 show perspective views of the  
17 actuator 50, showing how the torsion forks 46 are  

---

18 connected to the inner portion 14.

19  
20 The MRF actuator 50 can adapt semi-active damping of  
21 torsional and longitudinal movement with a  
22 combination of the pressure driven flow (/ valve  
23 mode) and direct shear mode of the MR fluid being  
24 applied.

25  
26 Fig. 12 shows a sixth embodiment of the present  
27 invention, namely an actuator 60 that is mounted in-  
28 line with the board 40.

29  
30 The electromagnet 20 is powered by power supply 62.  
31 The MRF chamber 28 is attached to the board 40, and

1 the outer portion 12 of the actuator 60 is attached  
2 to the shim 44.

3

4 Fig. 13 shows a perspective view of the actuator 60,  
5 as incorporated with a board 40.

6

7 Mounted with its axis parallel to the axis of the  
8 board, the MRF actuator can adapt semi-active  
9 damping of longitudinal movement with a combination  
10 of the pressure driven flow (/ valve mode) and  
11 direct shear mode of the MR fluid being applied.  
12 Torsional stiffness can be adapted by applying the  
13 direct shear mode to resist rotation of the inner  
14 relative to the outer.

15

16 Adaptive control of the damping is provided by an  
17 intelligent control system. Fig. 14 shows an

18 intelligent control system suitable for use with the  
19 damper shown in Fig. 9, while Fig. 15 shows an  
20 intelligent control system suitable for use with the  
21 damper shown in Fig. 12.

22

23 Integration of a parasitic power generator is  
24 preferable to powering the system from a battery. A  
25 piezo-ceramic power generator 70 (such as PZT - lead  
26 zirconium titanate) located at areas of concentrated  
27 load can be used to harvest power from deflections  
28 induced by the movement between the rider and the  
29 board.

30

31 The location of the generator could for example, be  
32 specified to be under the riders boot. For example,

1 the power generator could be a piezoelectric (lead-  
2 zirconium titanate - PZT) bimorph / piezoelectric  
3 (PZT) unimorph located in the minding foot-plate /  
4 between the binding assembly and the deck of the  
5 board.

6  
7 This is in contrast to presently available systems,  
8 which merely use the vibration caused by movement of  
9 the board to generate power. By placing the piezo-  
10 ceramic power generators 70 at strategic points  
11 where there is concentrated load and/or movement  
12 from the rider of the board when using it, enough  
13 power can be generated to power the electromagnet  
14 and ICU.

15  
16 The piezo-ceramic generator 70 located within the  
17 binding assembly (/between the binding and board)

18 can power an energy efficient network of control-  
19 actuator(s).

20  
21 An array of piezo (polymer) sensors (e.g.,  
22 polyvinylidenefluoride - PVDF) sensors 72 provides a  
23 self-powered vibration monitoring capability. An  
24 array of sensors 72 located within the beam section  
25 to be controlled can provide input to the control  
26 interface on longitudinal and torsional dynamic  
27 movement produced from surface induced impulses.

28

29 This system must be sufficiently energy efficient so  
30 that the power available to the electromagnet can  
31 sufficiently change the apparent viscosity of the MR  
32 fluid, resulting in a satisfactory improvement in

1 dynamic control. Therefore, the number of turns on  
2 the core of the electromagnet must be sufficient to  
3 generate a satisfactory on state, but be  
4 conservative in number to conform to the power  
5 constraints. The available energy and required  
6 control bandwidth must be considered for each  
7 application.

8  
9 The data provided by the sensors 72 can be used to  
10 determine the amplitude and frequency  
11 characteristics of board vibration induced as the  
12 board moves over the snow. Characteristics of the  
13 vibration can be used to determine environmental  
14 inputs (e.g., hard / soft packed snow), based on  
15 information pre-programmed into the ICU 74.

16  
17 The ICU 74 controls the power supply to the  
18 electromagnet 20 such that vibration amplitude and  
19 frequency may be controlled subject to the applied  
20 control algorithm (e.g., proportional control /  
21 proportional-integral-differential control / sky-  
22 hook algorithm / to a set value - up to a definable  
23 maximum).

24  
25 One or more MRF actuators may be mounted  
26 transversely, or with its axis parallel to that of  
27 the board as described above in order to provide  
28 multi-axis control.

29  
30 Another major application of the present invention  
31 is the incorporation of an actuator in the grip of  
32 sports equipment, such as for example tennis, squash

1 or badminton rackets; golf clubs; baseball or  
2 cricket bats; or polo mallets.

3  
4 Fig. 16 shows the application of an adaptive shock  
5 absorbing grips may integrated on a golf club 80.

6  
7 The MRF device 10 is integrated so that the axis is  
8 in-line with the axis of the shaft 82, with the  
9 inner component mounted to the shaft 82 and the  
10 outer making up the grip. Activation of the  
11 electromagnet mounted on the structural inner  
12 component results in an apparent viscosity change in  
13 the MR fluid between the inner and outer (grip),  
14 reducing relative movement in two axes and  
15 introducing an adaptable energy absorbing  
16 capability.

17  
18 A spring return to a neutral position is required.  
19 Sprung collars or bushes, such as those illustrated  
20 in Figs. 2-5, can be located between the seals,  
21 against the inner axle and outer cylinder (i.e., in  
22 the space between the shaft and the outer housing)  
23 to provide resistance to deflection that the MR  
24 fluid is able to dynamically control. Therefore,  
25 the spring is integrated in the damper assembly.

26  
27 A contact plate can interface the shock-absorbing  
28 grip with the sensor-control and power supply  
29 elements of the system.

30  
31 For this application, and application to handles of  
32 other devices, it is desirable to actively prevent

1 translation along and rotation about the shared  
2 central axis of the inner member relative to the  
3 outer member, so the off state force in these  
4 degrees of freedom needs to be raised.

5

6 This is possible by specifying seals with  
7 appropriate elasticity to prevent noticeable  
8 movement.

9

10 Again, integration of a parasitic power generator is  
11 preferable to powering the system from a battery. A  
12 piezo-ceramic power generator located at a point of  
13 concentrated load can be used to harvest power from  
14 deflections induced by the movement between the head  
15 or club, the shaft, and the handle (where the grip  
16 is located). The piezo-ceramic generator can power  
17 an energy efficient network of control-actuator(s),  
18 with piezo (polymer) sensors providing self-powered  
19 vibration monitoring capability.

20

21 PVDF sensors are proposed to provide a self-powered  
22 vibration monitoring capability. An array of  
23 sensors located within the shaft can provide input  
24 to the control interface on transmitted vibrations  
25 resulting from shock induced impulses.

26

27 A further identified application of multi-axis  
28 adaptive semi-active control of dynamic movement is  
29 in bicycle and motorbike handles. Sports bikes with  
30 low handles result in a riding position that puts  
31 weight on the rider's wrists, with fatigue  
32 compounded by any shock induced vibration that is



1 not sufficiently damped by the main front  
2 suspension. One or more multi-axis MRF device can  
3 be located in the bike handles as a secondary system  
4 to absorb shock and reduce wrist fatigue.

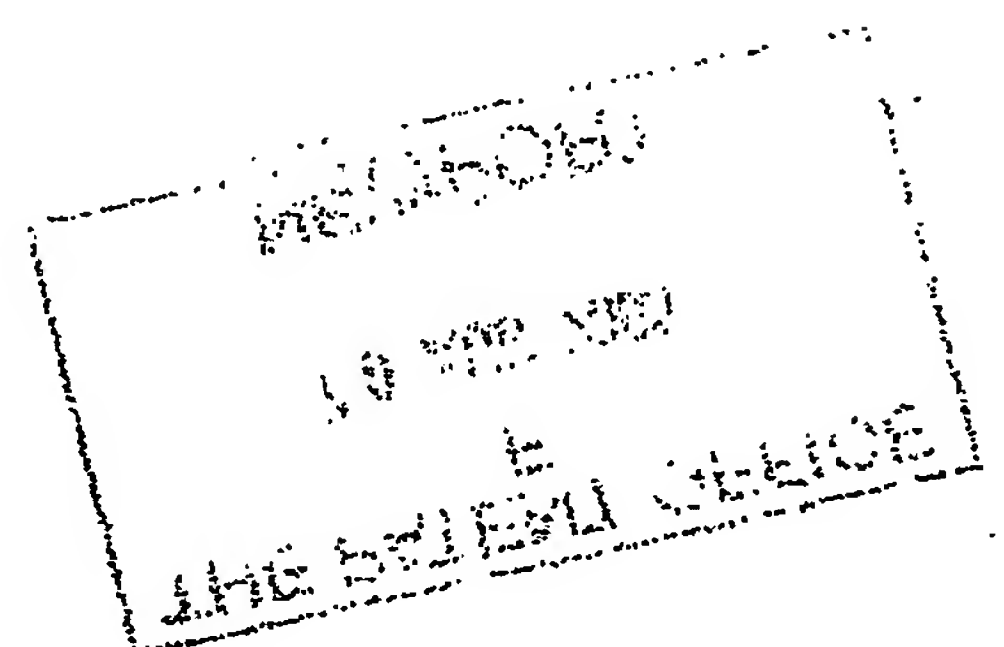
5  
6 In a motorcycle application there is sufficient  
7 capacity to power the MRF device(s) with negligible  
8 performance consequences.

9  
10 Applied to bicycles, although it is possible, it is  
11 advantageous not to power the MRF device(s) from the  
12 powertrain (i.e., rotation of the pedals / the  
13 wheels) as this will reduce performance. An  
14 alternative, to a dynamo powering the MRF device(s)  
15 from the powertrain, is a parasitic power generator  
16 - preferably located between the bicycle and rider,  
17 at a position, where there is a concentrated load.

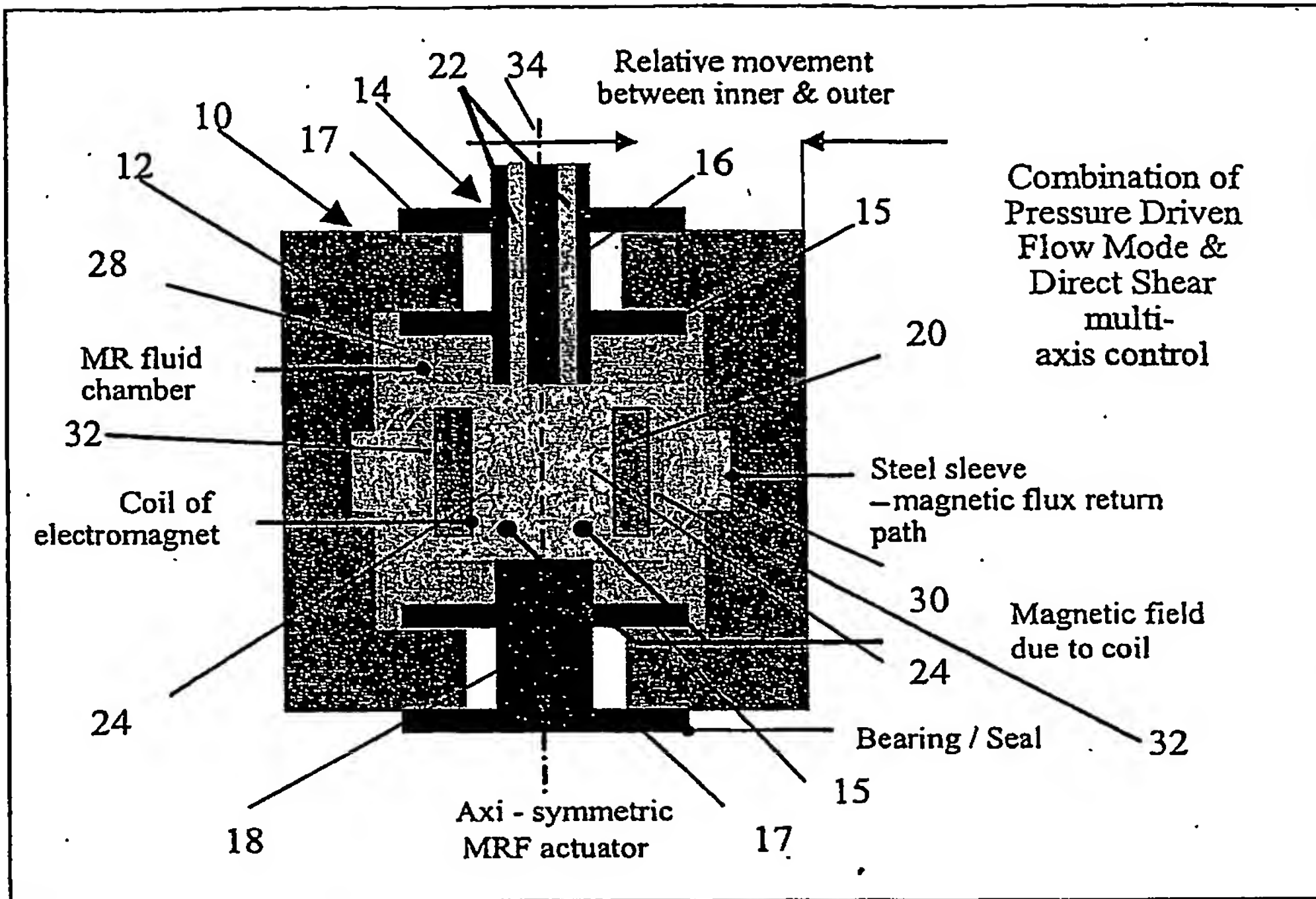
18  
19 A piezo-ceramic power generator located in the seat-  
20 post can be used to harvest power from deflections  
21 induced by the movement of the rider on the seat.  
22 The piezo-ceramic generator can power an energy  
23 efficient network of control-actuator(s), with piezo  
24 (polymer) sensors providing self-powered vibration  
25 monitoring capability.

26  
27 Improvements and modifications can be made to the  
28 above without departing from the scope of the  
29 present invention. In particular, the application of  
30 the invention to be incorporated in specific devices  
31 is not limited to the list of specific devices  
32 herein. Furthermore, it will be apparent that the

- 1 specific geometry of, for example, the layout of the
- 2 sensor array or of the parasitic power generators
- 3 may be varied as appropriate for the specific
- 4 application being considered.
- 5

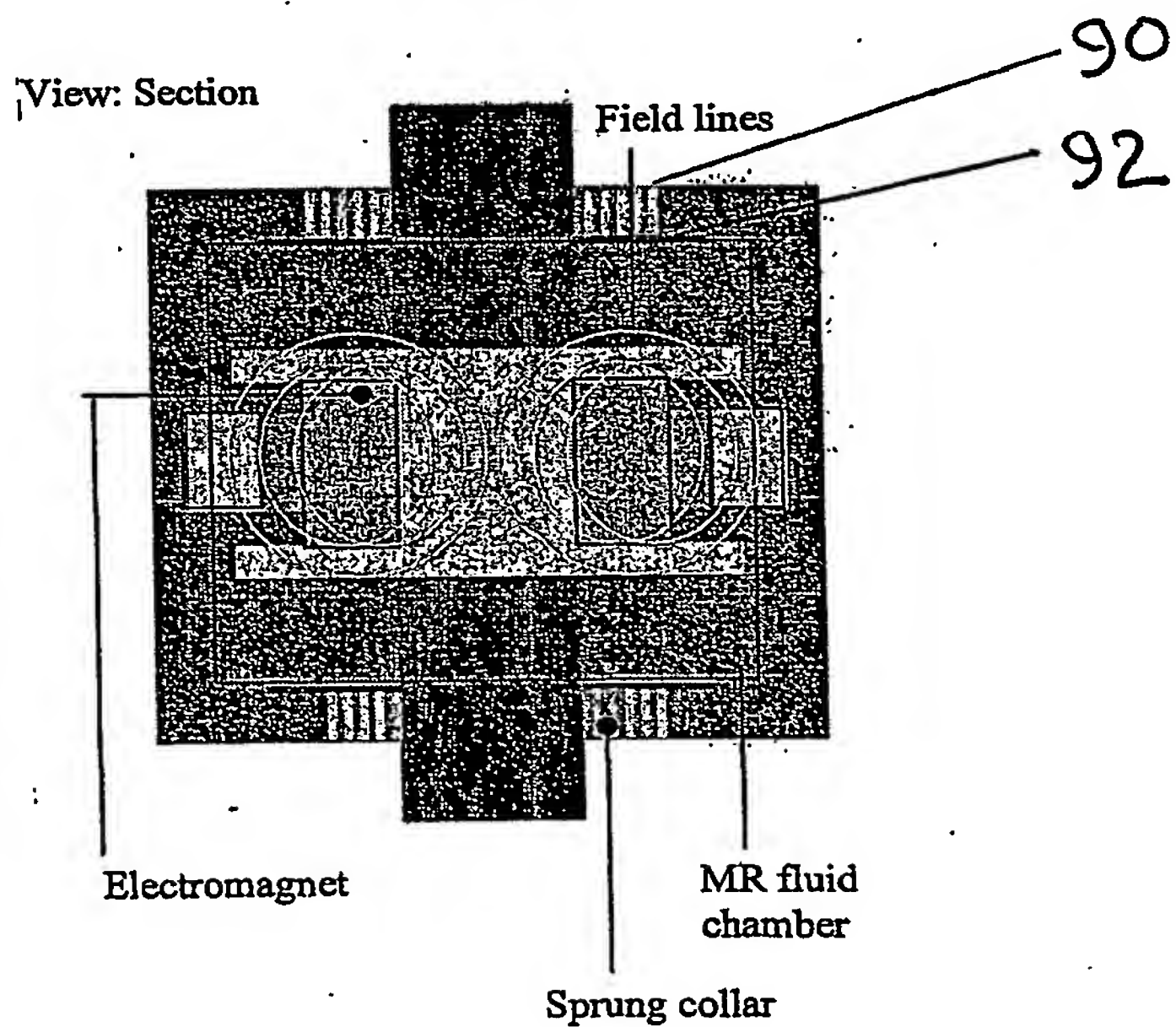


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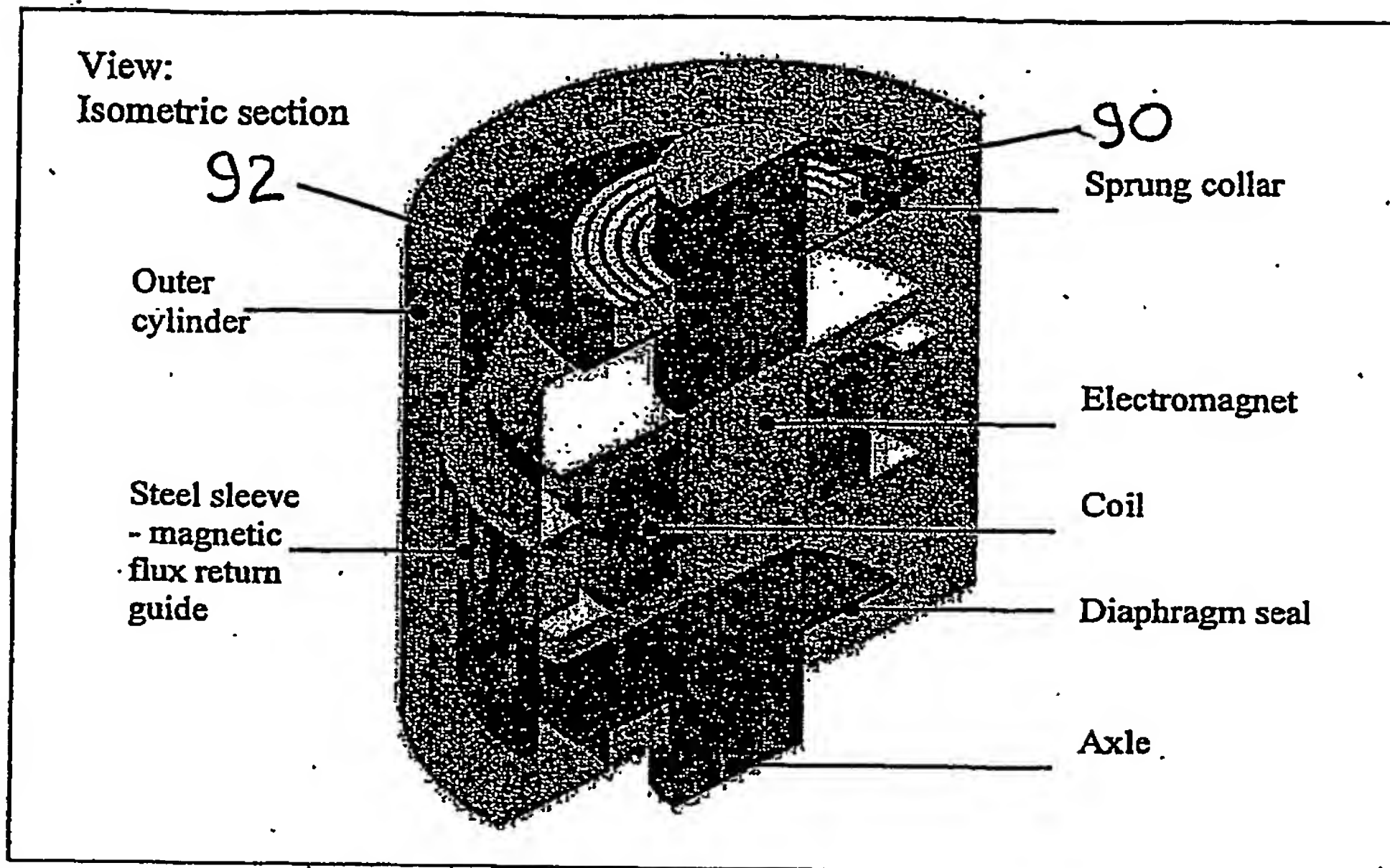
Section: multi-axis MRF device schematic

Fig.1



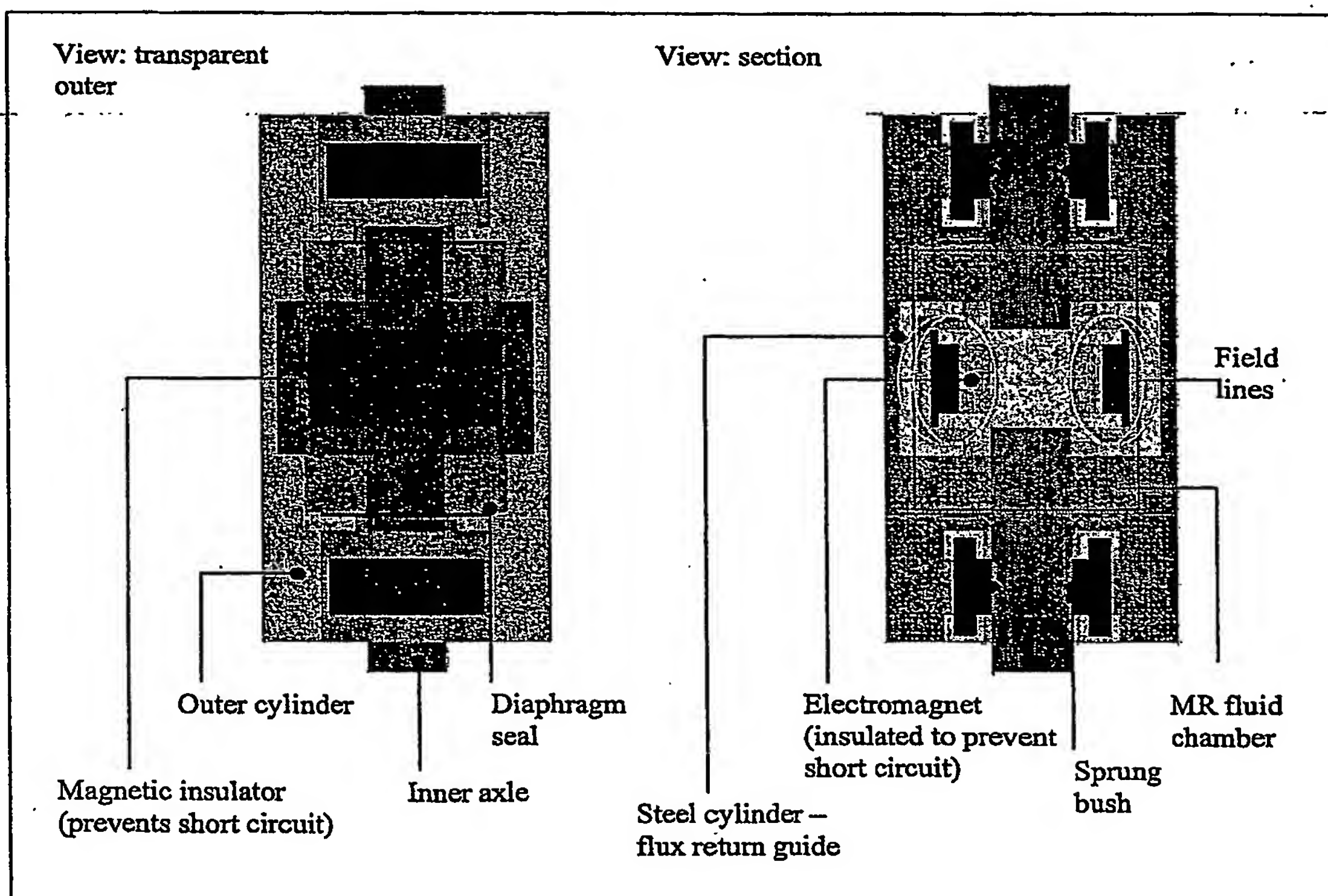
Sleeve flux return guide

Fig.2



Isometric section – MRF actuator with sleeve flux return guide

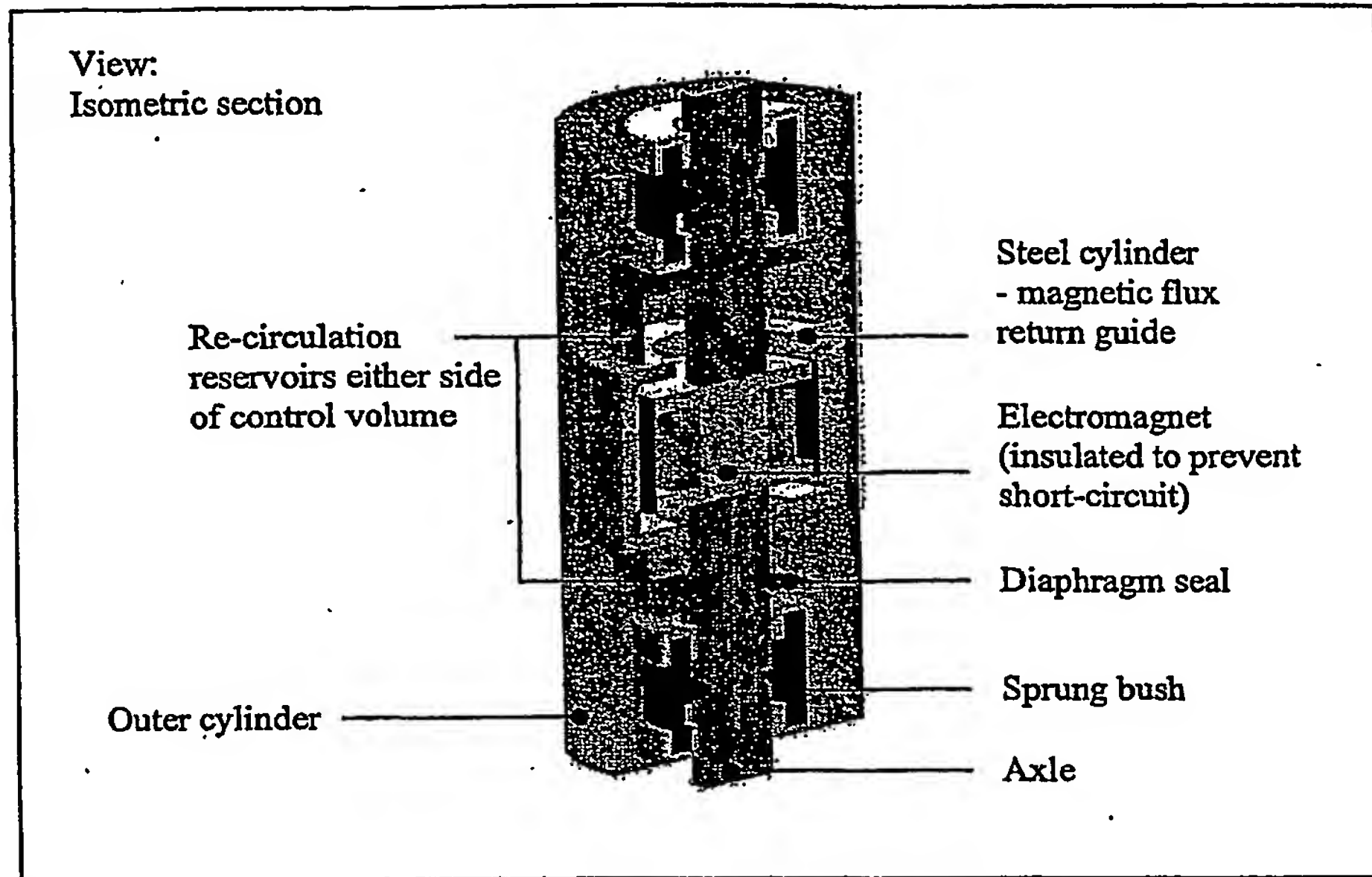
Fig.3



Cylinder flux return guide

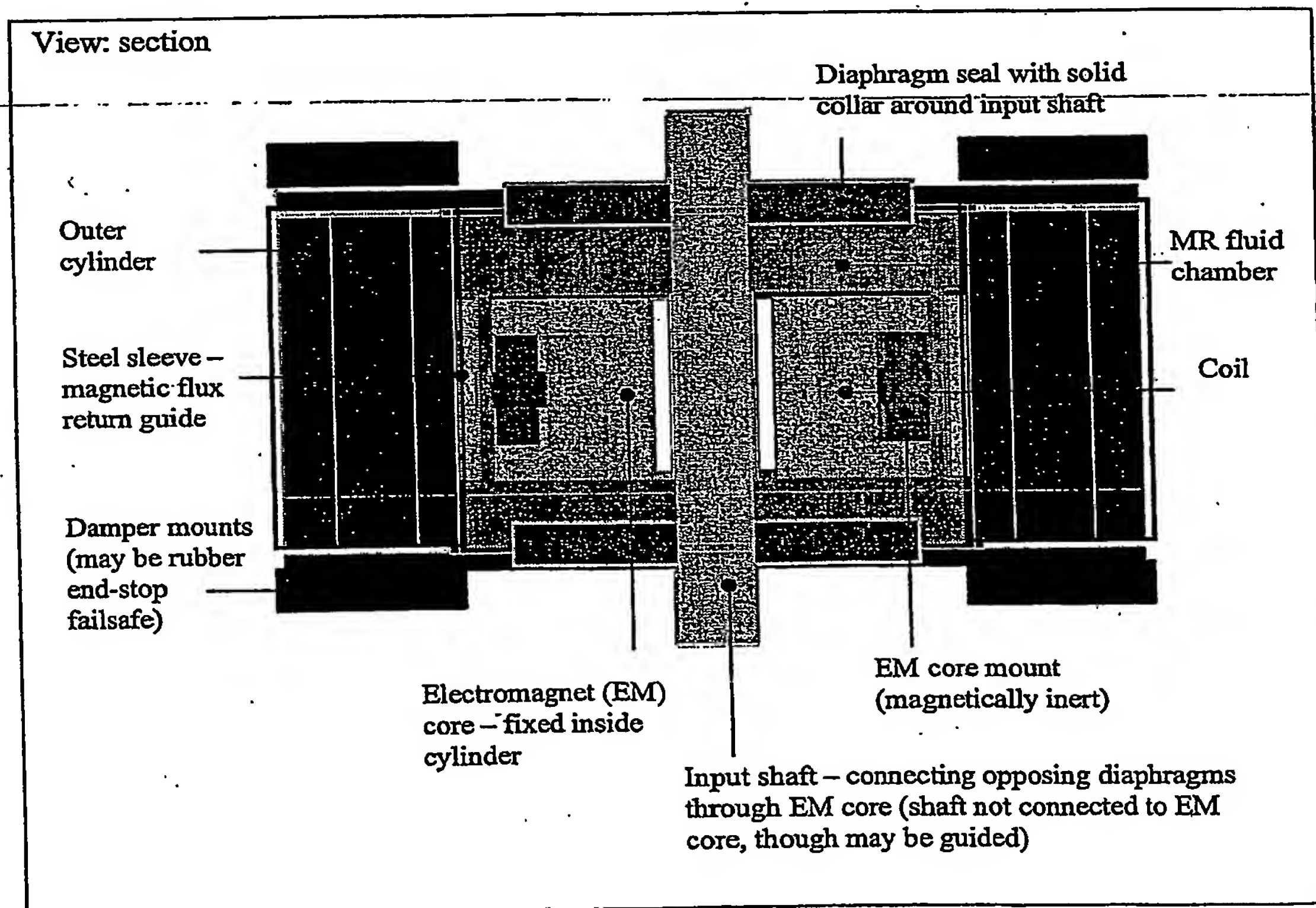
Fig.4





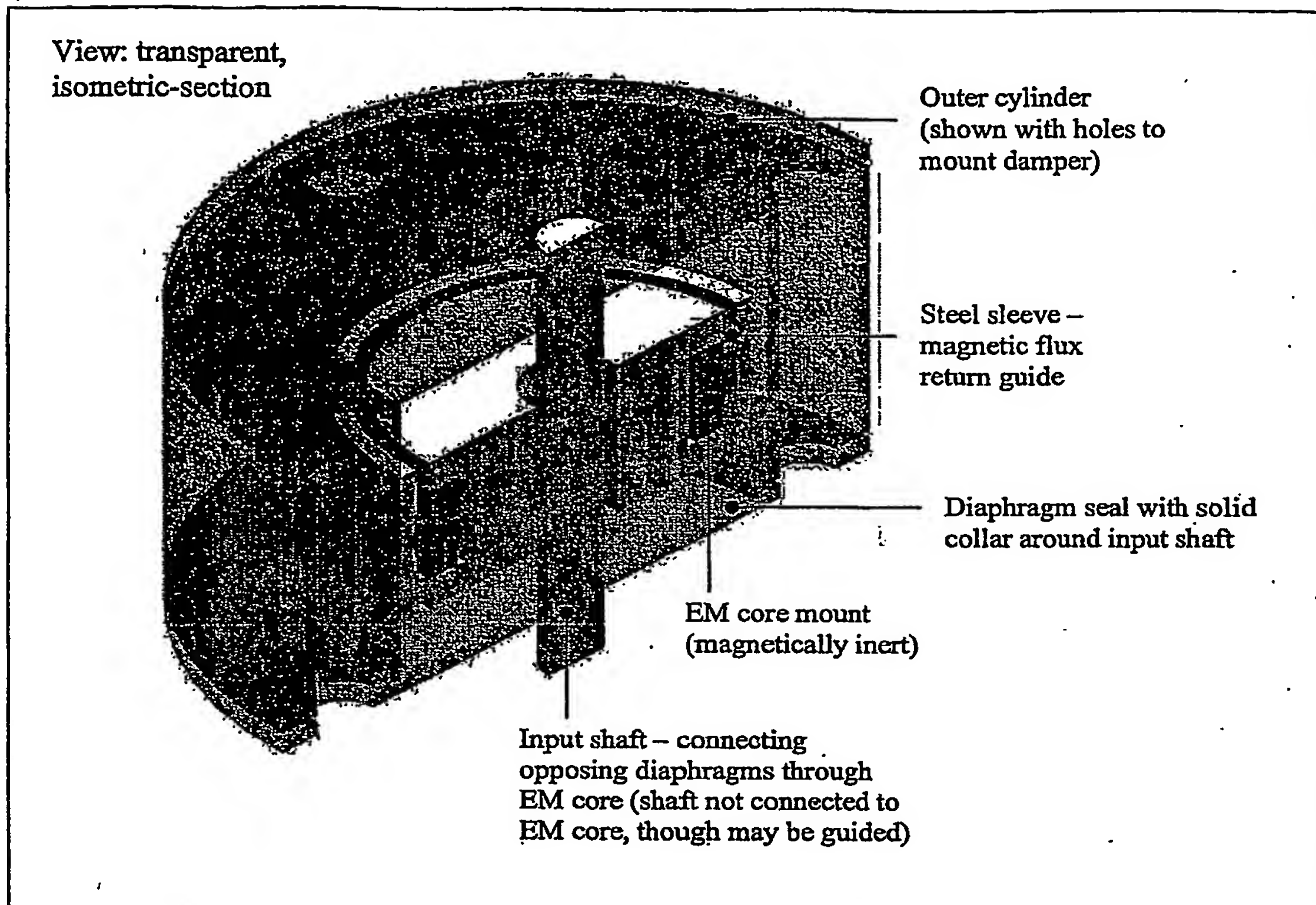
Isometric section – MRF actuator with cylinder flux return guide

Fig.5



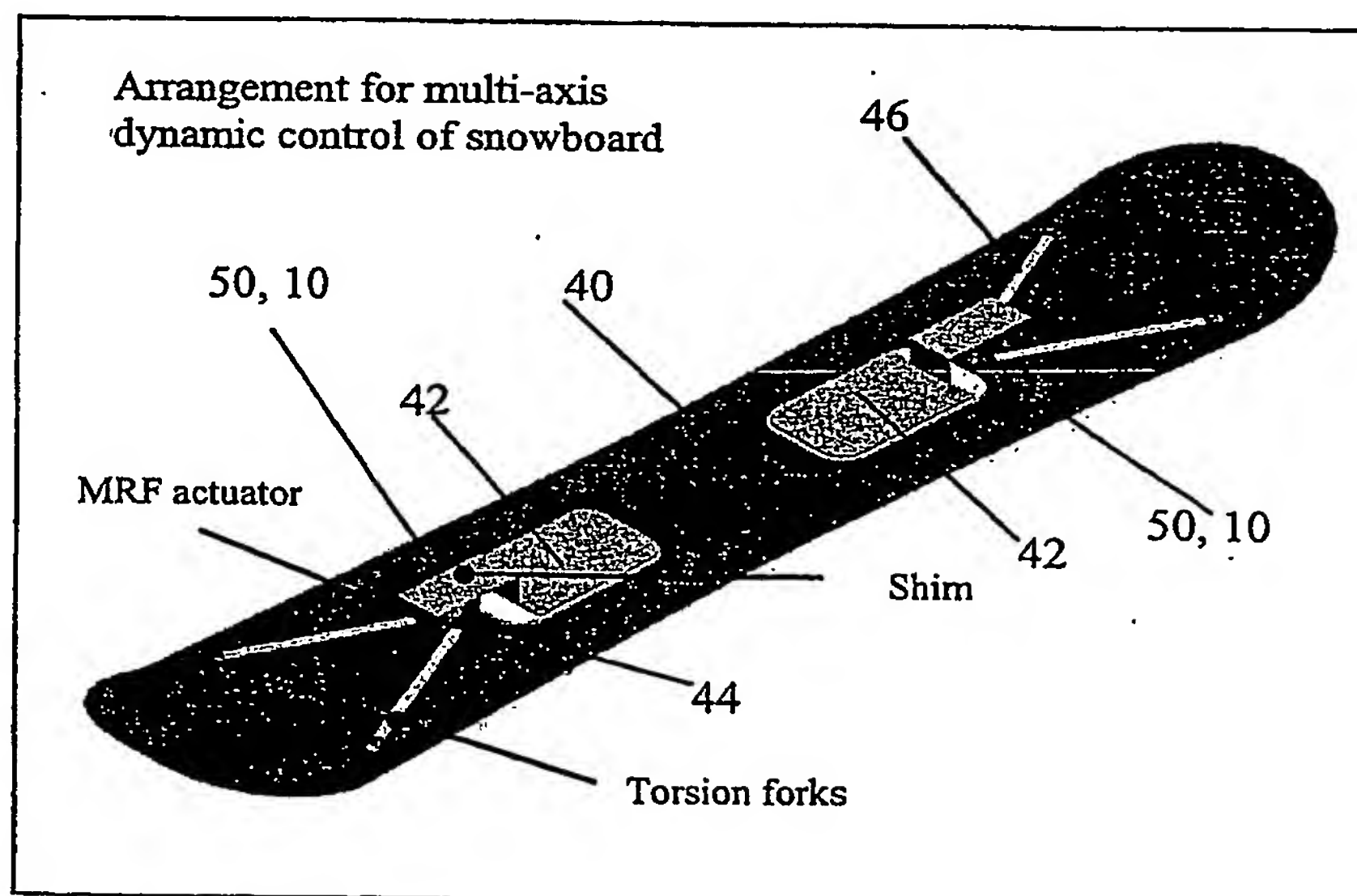
Section: connected diaphragm activated MRF actuator

Fig.6



Isometric view: connected diaphragm activated MRF actuator

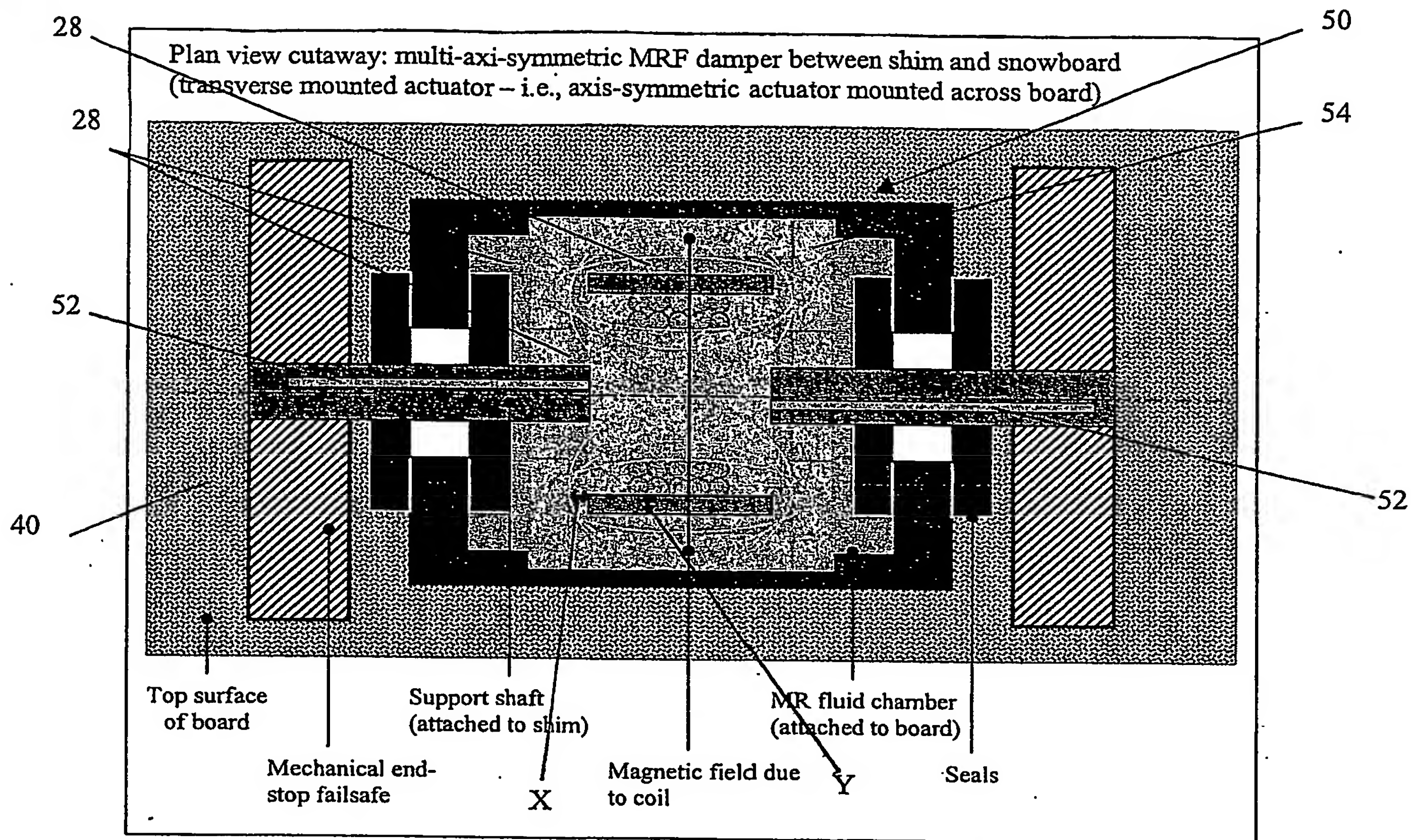
Fig.7



Concept 3 Snowboard

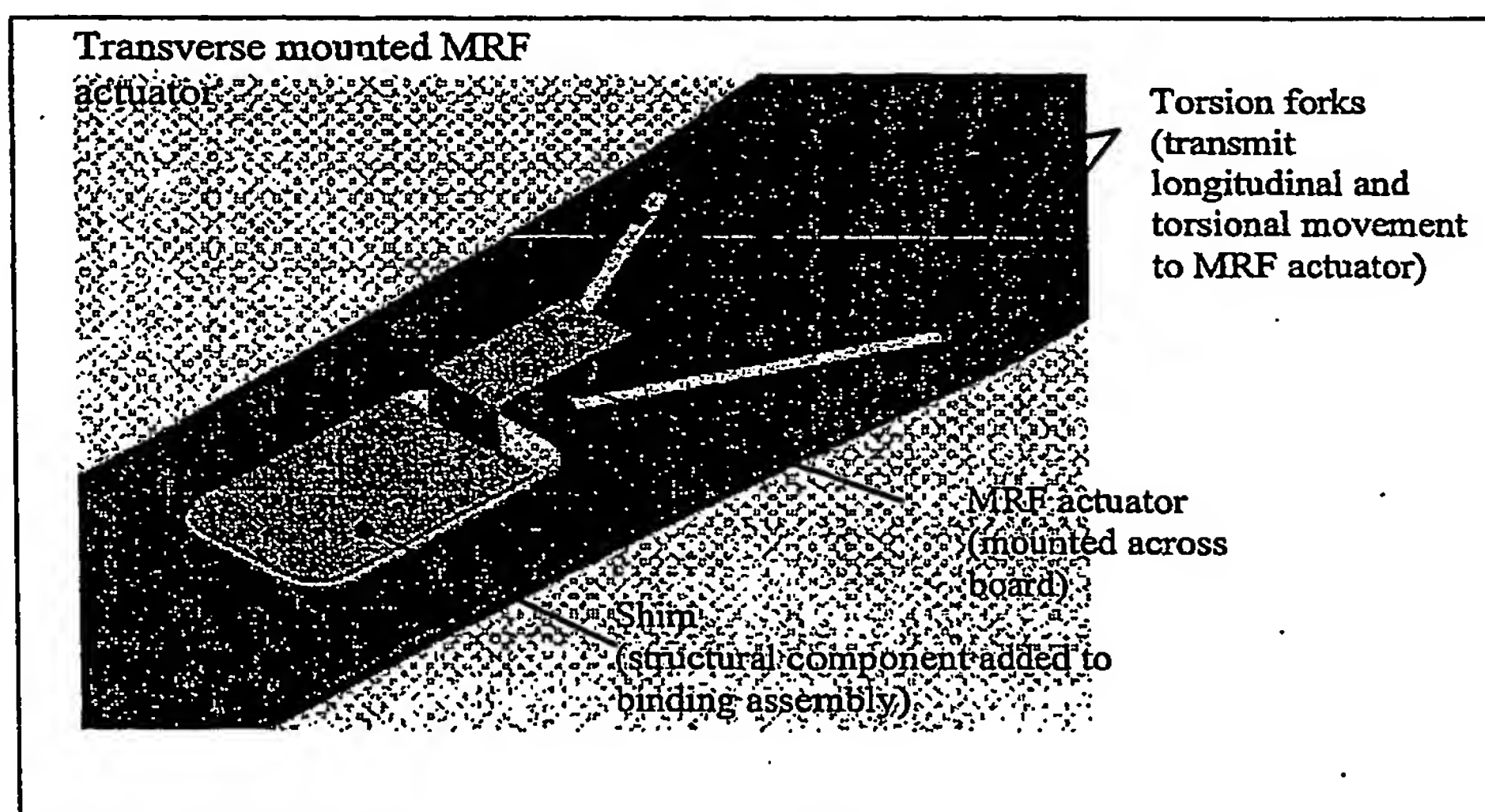
Fig.8





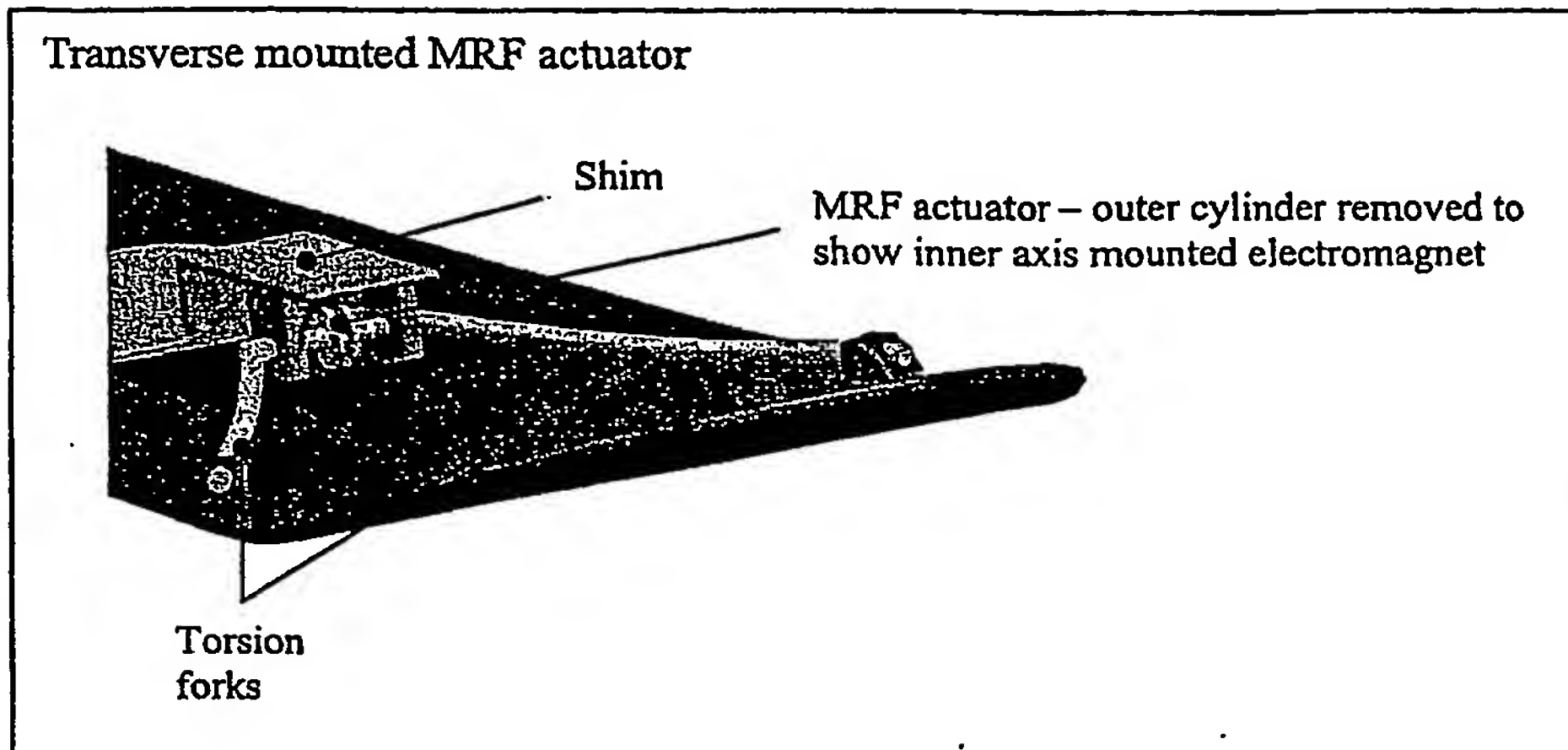
Schematic of transverse mounted actuator between shim and board

Fig.9



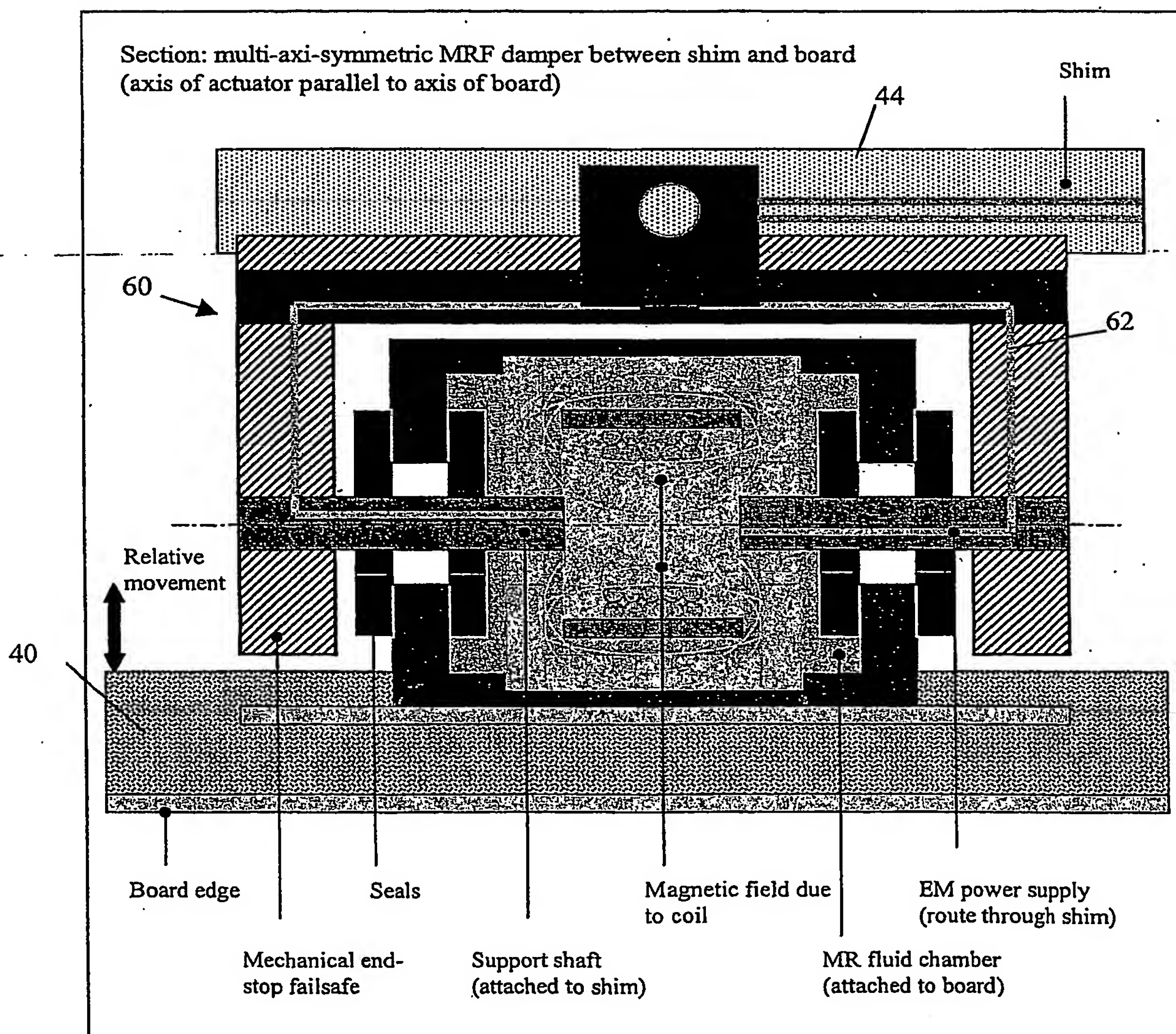
Torsion forks

Fig.10



Adaptive longitudinal and torsional semi-active damping

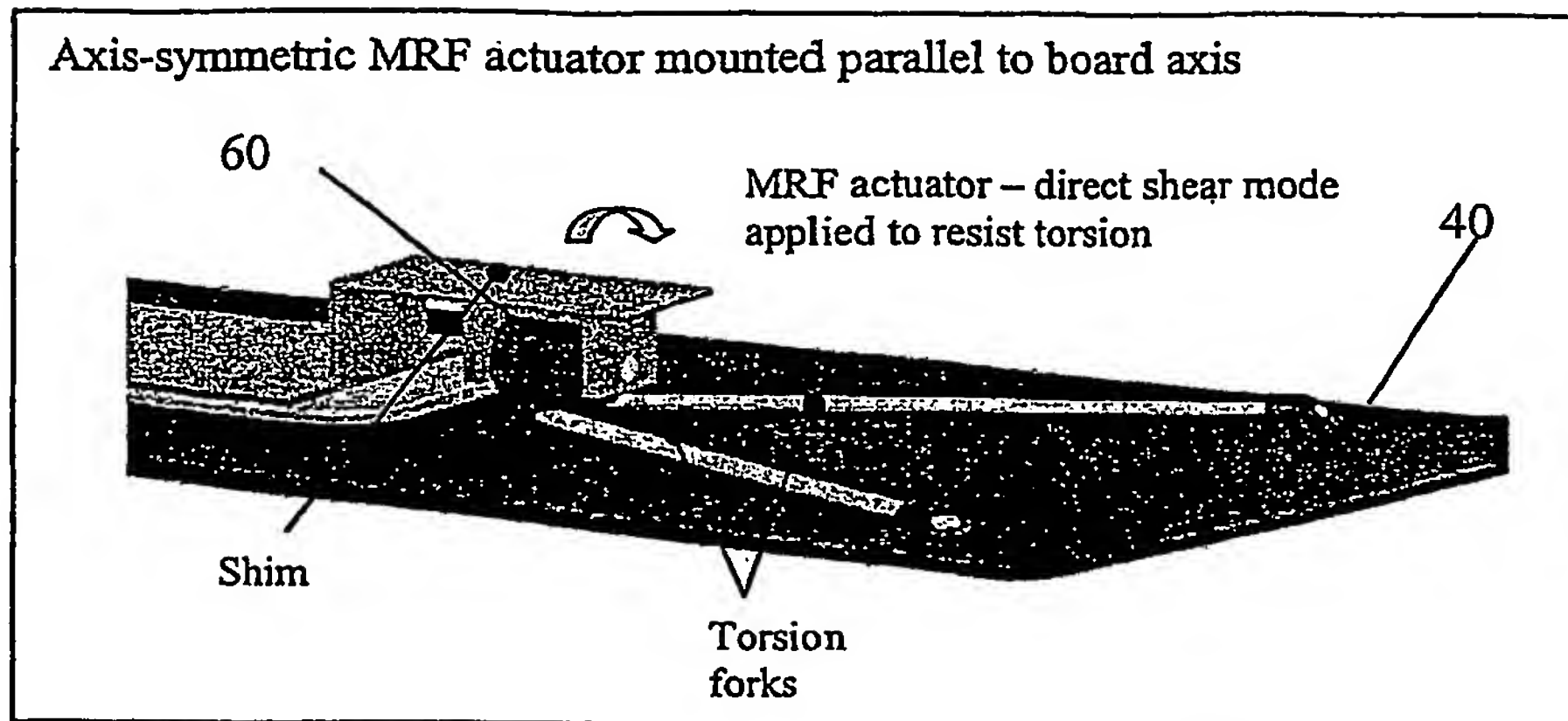
Fig.11



Schematic of MRF device mounted between shim and board

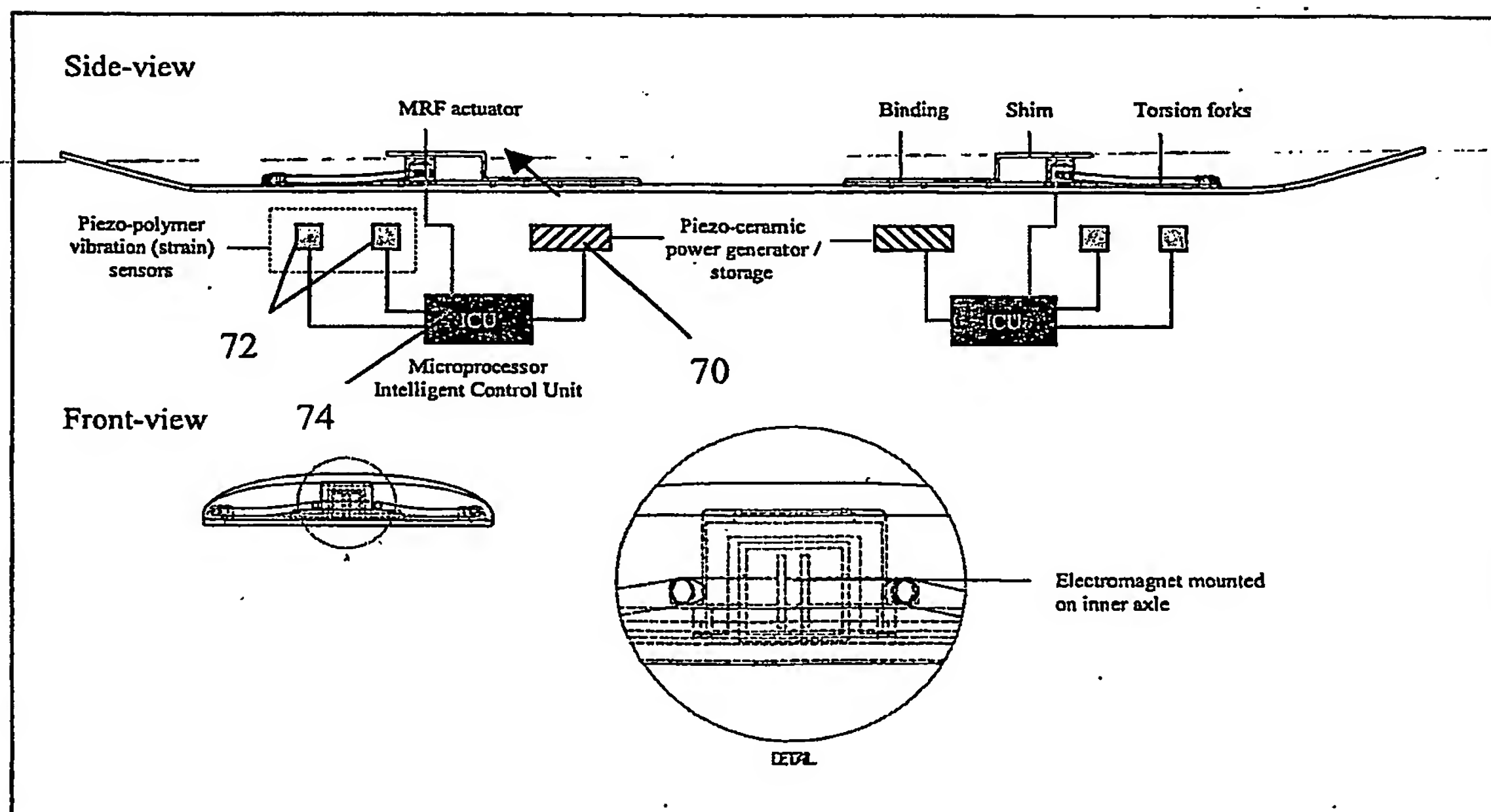


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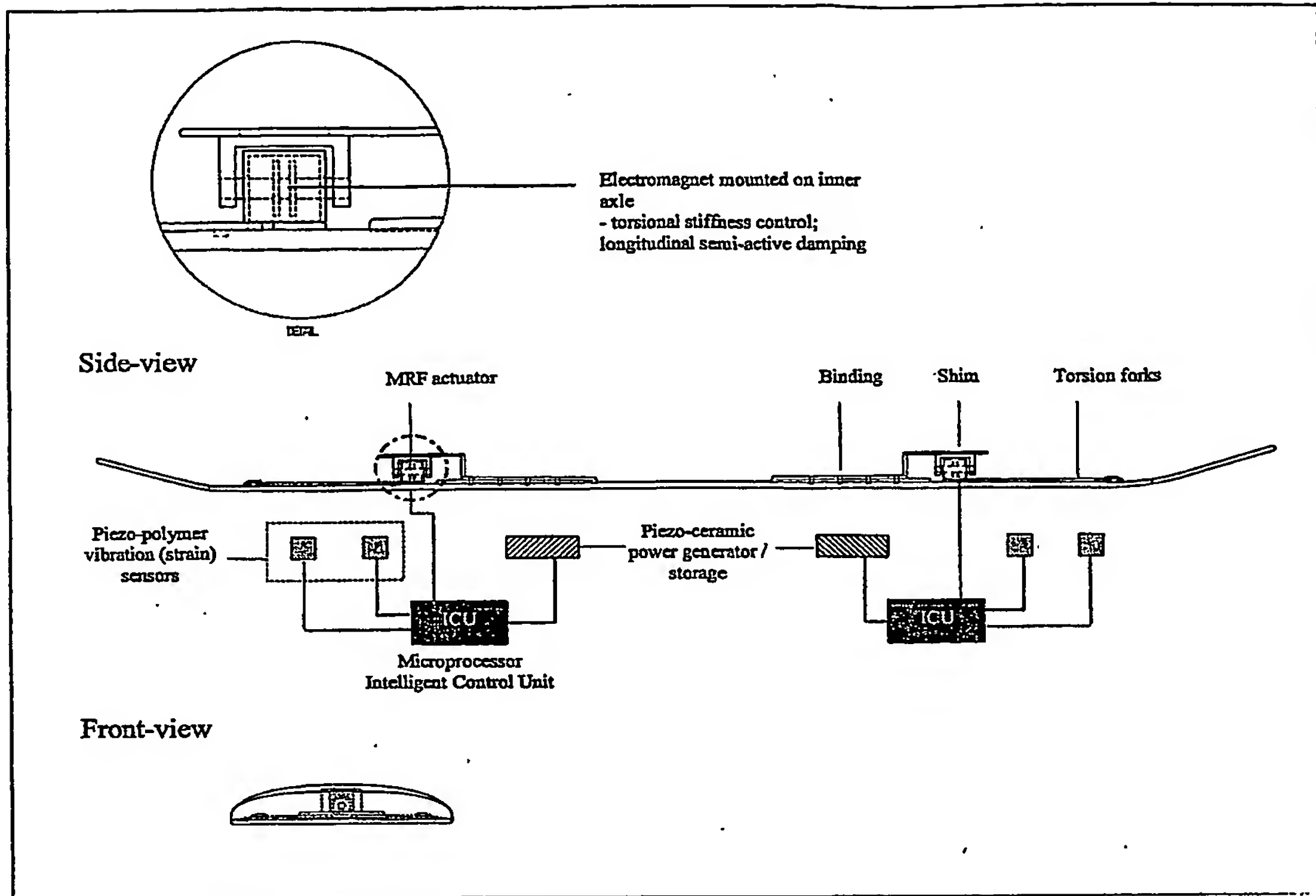
Adaptive torsional stiffness control

Fig.13



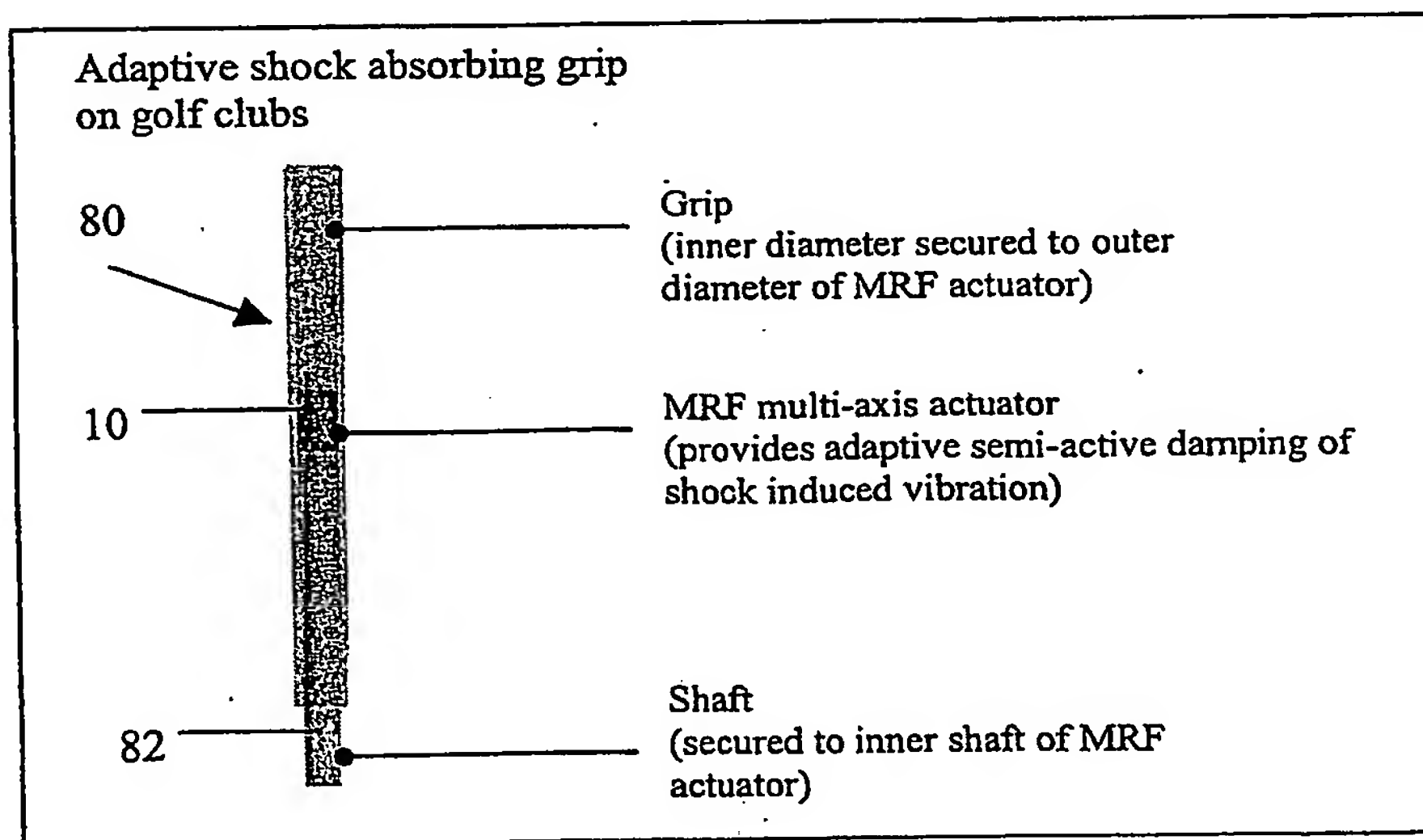
Sketch of transverse mounted actuator with control schematic

Fig.14



MRF actuator mounting sketch with control schematic

Fig.15



Multi-axis adaptive semi-active damping on golf clubs

Fig.16

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